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RELATION BETWEEN EARTH TIDE OBSERVATIONS AND SOME OTHER DATA

por

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RELATION BETWEEN EARTH TIDE OBSERVATIONS AND SOME OTHER DATA

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1. Introduction.

Recently (Venedikov, 1988) it was proposed a new model for the study of the relation between Earth tide observations, say G and the air pressure data, say P . Here we shall give the results from the application of the model to a large record obtained in Pecny and to a shorter record in Sofia.

It is well known that the most important influence on the Earth tide observations is that of the ocean and sea tides. It is taken into account through computations made on a co-tidal map, now most often the map of Schwiderski. In such a way only the pure harmonic tidal oscilations of the water level are considered.

At a given coastal place it is certainly possible to have deviations in the water level. First, due to local particularities of the water bassin the tides may be shifted in amplitude and phase compared to the tides predicted by the co-tidal map. Second, the level may be influenced by meteorological factors as air pressure and wind (meteorological tides). At the same time just the closest water masses have the strongest effect especially on the coastal Earth tide stations.

In principal in the model mentioned abouve we can use as P any phenomena which is expected to influence the Earth tide observations. In particular, for a coastal station, it could be interesting to use as P the water level. Thus we would obtain some direct estimates of the effect of the closest ocean or sea zones. It seems that this may be a helpful addition to the computations made on the co-tidal map.

We have realized such an experiment with the coastal gravity station Cueva de los Verdes (Lanzarote). The results are also given in the present paper.

2. The model used.

We shall briefly discuss the model with some precising explanations.

Let $\bar{S}$ is a vector representing a periodic component of P . We suppose that $\bar{S}$ generates a component $\bar{Q}$ with the same periodicity in the Earth tide record G . If $Q = |\bar{Q}|$ and $S = |\bar{S}|$ are the corresponding amplitudes and b is the angle (phase shift) between $\bar{S}$ and $\bar{Q}$ our hypothesis is

$$Q = B.S \;, \quad B = \text{const.} \quad \text{and} \quad b = \text{const.} \tag{1}$$

Let δ_s , $\varkappa_s$

$$\xi_s = \delta_s \cos \varkappa_s \quad \text{and} \quad \eta_s = - \delta_s \sin \varkappa_s \tag{2}$$

are parameters of $\bar{S}$ defined in a similar way as usual Earth tide parameters. This statement means that if we analyse P formally as if P are Earth tide data we shall obtain some estimates of the quantities (2).

Let $\bar{A}(\delta, \varkappa)$ is an observed tidal component of G of the same type as $\bar{S}$, i.e. D, SD or TD. Observed means that $\bar{A}$ incorporates the effect $\bar{Q}$ of $\bar{S}$. And let $\bar{A}_o(\delta_o, \varkappa_o)$ is the same component free from this effect, i.e.

$$\bar{A}_o = \bar{A} - \bar{Q} \quad . \tag{3}$$

If we use the quantities

$$\begin{aligned} \xi &= \delta \cos \varkappa , & \eta &= - \delta \sin \varkappa , \\ \xi_o &= \delta_o \cos \varkappa_o , & \eta_o &= - \delta_o \sin \varkappa_o \end{aligned} \tag{4}$$

the following simple relations come from (1) and (3)

$$\begin{aligned} \xi &= \xi_o + B_1 \xi_s - B_2 \eta_s \\ \eta &= \eta_o + B_1 \eta_s + B_2 \xi_s \end{aligned} \tag{5}$$

where $\quad B_1 = B \cos b \quad$ and $\quad B_2 = B \sin b \qquad (6)$

The quantities ξ and η as defined by the first equations of (4) are the unknowns used in the ordinary tidal analysis. If we want to take into the account the effect of P, respectively $\bar{S}$ and $\bar{Q}$, we have to replace ξ and η by the new unknowns ξ_o and η_o and include two more unknowns the regression coefficients B_1 and B_2.

However this cannot be directly done through the expressions (5) with constant ξ_s and η_s. The equations used in the analysis will become linearily dependent. This reflects simply the fact that in principle there are no means to separate from the tidal data a stable constant meteorological or any other kind of wave with a tidal frequency.

Nevertheless the expressions (5) can be used if we consider on the variation with time of $\bar{S}$, ξ_s and η_s.

In the first stage of the analysis we process a filtering of independent short intervals of the tidal record. Let T' is the central epoch of a given filtered interval. Through the technics proposed by Venedikov (1981) and Xu Houze (1984) we can get $\xi_s(T)$ and $\eta_s(T)$ separately for D, SD and TD, through the filtering of the data P.

Let x_s and y_s are the mean values of $\xi_s(T)$ and $\eta_s(T)$ respectively and let

$$\Delta x_s(T) = \xi_s(T) - x_s \quad , \quad \Delta y_s(T) = \eta_s(T) - y_s \qquad (7)$$

Then the expressions (5) become

$$\xi = \tilde{\xi}_o + B_1 \Delta x_s(T) - B_2 \Delta y_s(T)$$

$$\eta = \tilde{\eta}_o + B_1 \Delta y_s(T) + B_2 \Delta x_s(T) \qquad (8)$$

where

$$\tilde{\xi}_o = \xi_o + B_1 x_s - B_2 y_s$$

$$\tilde{\eta}_o = \eta_o + B_1 y_s + B_2 x_s \qquad (9)$$

It is these equations (8) which can be used in the analysis. As a result directly from the processing we shall obtain estimates of the quantities (9) which are still charged by the total effect of $\bar{S}$, respectively of P. In the same time we shall get the estimates of the regression ceefficients B_1 and B_2. Later we can get the corrected numbers ξ_o and η_o from (9) i.e.

$$\xi_o = \tilde{\xi}_o - (B_1 x_s - B_2 y_s)$$

$$\eta_o = \tilde{\eta}_o - (B_1 y_s + B_2 x_s) \qquad (10)$$

3. Some results for the air pressure.

We have analysed formally as an Earth tide record a large air pressure series from Pecny prepared by Broz and Simon It covers in total an interval of 15.9 years, 1.09.1970 - 30.07.1986 with the following more important interruptions:

4 11.1971 - 30.01.1974, 20.08.1975 - 20.04.1976 and 1.09.1 981 - 25.01.1982. The results - amplitudes, phases and mean square errors (R.M.S.) are presented in Table 1. The original data are given in 0.1 mm mercury, while the amplitudes are expressed in mm mercury. The phases are related to the corresponding theoretical tidal phases.

Statistically significant and relatively important amplitudes are observed only at the waves S1, S2, S3 and some close tides -(P1,S1,K1,PSI1,PHI1), (T2,S2,K2). The evident conclusion is that the main oscilations in the atmosphere are of meteorological and non-tidal origin. The only clearly observed tidal wave is M2 with a small but very significant amplitude.

It is interesting that the relation D/SD/TD for the standard deviation is similar to this relation for the analysis of Earth tide data.

These series, after a corresponding reduction of the length, were processed together with a large record of the gravimeter GS 15/228 at the same station Pecny provided by S.Holub, J.Broz and Zd.Simon. It covers a time interval of 8.4 years, 22.04.1976 - 25.09.1984. The neto amount of the data is 48 708 hourly ordinates. The results are presented in Table 2.

By the same gravimeter GS 15/228 observations were made in Sofia during 1 year. A record 12.12.1981 - 4.12.1982 was processed together with parallel air pressure data from the meteorological station in Sofia. The results are presented also in Table 2.

If we take into account the precision in Sofia there is a rather good coincidence in the coefficients B_1 and B for

D tides in the two stations. For SD the results in Sofia are not satisfactory.

The lower precision in the determinations of the coefficients in Sofia can be only partly explained by that the record is shorter.

4. Direct relation between Earth tide and sea tide observations.

The motivation for this experimental study was given in § 1 .

In the station Cueva de los Verdes (Lanzarote) Earth tide observations are made by the gravimeter LaCoste and Romberg No 434. The station is situated closely to a maregraphic station. We have used two parallel series from these stations with length 0.8 year - 11.07.1987 - 27.04.1988.

The maregraphic data were submitted to an analysis as gravity Earth tide data. The results are presented in Table 3 as they are outprinted by the computer. The amplitudes are expressed in cm.

The SD tides are more important and better determined than the D tides. Some of the D tides are statistically unsignificant : NO1, J1 and OO1. The SD tides as well as M3 are all significant. It is interesting that there is perfect coincidance in phase between M2 and the tidal potential.

The results from the analysis of the gravity data are presented in Table 4. It is very remarkable that with the exception of M3 all factors are very small, especially for SD. It is possible that this is due to the coastal situation of the station and a strong particular influence of the sea.

References.

Venedikov, A.P., 1981. Determination of the tidal parameters from short intervals in the analysis of Earth tide records. BIM, 85

Venedikov, A.P., 1988. A model for the study of the effect of the air pressure on the Earth tide data. BIM, under press.

Xu Houze, 1984. Harmonic analysis for short data using Venedikov's filters (in chinese). Crustal deformations and Earthquake, V.4, No 2, Wuhan.

In the same Table 4 are given the coefficients B

B_2 , B and the angle b which are determined by the common processing of both series of data. These coefficients are significant for D and SD .

It will be interesting to calculate the corrected parameters for the gravity M2 after the expressions (10).

As the phase shift $\varkappa$ is small for M2 for both Earth and sea data from (10) we have approximately

M2 :

$$\delta_o(\text{corrected}) = \delta_o(\text{gravimetric}) - B_1 . \delta(\text{maregraphic})$$

$$= 1.014 + 0.103 \times 1.130 = 1.130$$

This is still somewhat low value of δ but, in our opinion, it is remarcable that the correction is in the right sense. It is easy to verify that the corrections after (10) of all more important tides are in the sense to rise considerably the values of δ .

Table 1

Station Pecny, Air pressure, tidal analysis.

wave	amplitude	R.M.S.	phase diff.	R.M.S.
		D tides		
SIGQ	0.005	±0.007	24.269	± 78.843
2Q1	0.005	0.007	144.091	89.179
SIG1	0.01	0.007	256.746	39.766
Q1	0.017	0.007	-11.963	23.244
RO1	0.017	0.007	111.915	23.423
O1	0.011	0.007	98.762	34.709
TAU1	0.011	0.006	15.312	33.368
NO1	0.006	0.005	180.944	53.832
CHI1	0.012	0.006	112.561	30.704
PI1	0.003	0.007	76.278	121.361
P1	0.054	0.007	249.291	6.942
S1	0.066	0.010	41.231	9.124
K1	0.038	0.007	203.246	10.143
PSI1	0.010	0.007	-44.816	38.088
PHI1	0.014	0.006	103.809	25.059
TETA	0.005	0.006	190.929	72.125
J1	0.011	0.006	-11.079	30.267
SO1	0.020	0.006	236.171	18.109
OO1	0.014	0.005	98.155	21.583
NU1	0.008	0.005	267.313	35.263
		SD tides		
EPS2	0.003	0.002	162.070	43.573
2N2	0.001	0.002	190.021	176.205
MU2	0.003	0.002	76.455	38.704
N2	0.001	0.002	11.905	98.759
NU2	0.005	0.002	64.106	21.820
M2	0.010	0.002	119.242	11.042
LAMB	0.002	0.002	107.308	61.656
L2	0.001	0.002	-30.095	63.038
T2	0.015	0.002	-48.854	7.237
S2	0.151	0.002	193.825	0.752
K2	0.020	0.002	184.632	5.159
ETA2	0.001	0.002	127.047	146.158
2K2	0.002	0.001	-1.850	29.157
		TD tides		
M3	0.001	0.001	13.929	112.531
S3	0.010	0.001	209.238	4.716

Standard deviations D 1.67, SD 0.52 TD 0.22

Note: the amplitudes are in mm mercury.

Table 2

		B_1	R.M.S.	B_2	R.M.S.	B	b
Station Pecny	D	-0.416	±0.007	0.024	±0.007	0.417	176.74°
	SD	-0.235	0.023	0.032	0.024	0.237	172.86
Station Sofia	D	-0.471	0.047	0.093	0.045	0.481	168.78
	SD	-0.081	0.110	0.057	0.112	0.099	144.69

The unit of the coefficients B_1 , B_2 and B is μgal/mbar

Table 3

```
STATION                 DONNEES MAREGRAPHYQUES         ESPAGNE
29  9  0 N   -13 26   0 E            H     0M


LEAST SQUARE ANALYSIS/VENEDIKOV/74,PROG.SV.-ICET-DUCARME,MELCHIOR,VENEDIKOV
FILTERS ON  30 HRS,NR 102,202,301,          ELIM.POWERS D   2 SD 1 TD 1
COMPONENTS S1  O1   S2  N2   M3
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID (SKALSKY)
COMPUTER CENTRE UNIVERSITY COMPLUTENCE, MADRID
COMPUTER IBM 4381                                    PROCESSED ON 21.09.88

NORMALIZATION FACTOR    -1.0000
INERTIAL CORRECTIONS INTRODUCED

TIME INTERVAL    0.8 YEARS    287.4 DAYS    5580 READINGS    8 BLCKS   WEIGHTS
G*** 870711/870818 870903/871008 871011/871013 871110/871129
G*** 871202/880214 880218/880305 880307/880314 880316/880427
```

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
105.-139.	65	Q1	1.527	0.201	0.3018	0.0397	120.522	7.484	6.77	168.8
143.-149.	26	O1	4.348	0.214	0.1046	0.0081	77.047	2.809	29.95	171.9
152.-158.	22	NO1	0.252	0.190	0.1211	0.0913	-31.750	41.698	2.20	-176.5
161.-164.	13	P1	1.437	0.231	0.1169	0.0188	-27.189	9.401	12.92	-177.1
165.-168.	20	K1	5.335	0.216	0.1436	0.0058	-26.312	2.286	37.56	-176.4
172.-177.	22	J1	0.055	0.179	0.0263	0.0860	-89.978	187.254	2.41	-178.7
181.-1*3.	37	OO1	0.066	0.115	0.0580	0.1014	202.267	97.621	1.38	-179.0
207.-2*5.	155	M2	57.353	0.834	1.0020	0.0146	-1.820	0.781	9.26	-168.7
207.-23*.	41	2N2	1.778	0.032	1.2258	0.0362	33.340	1.690	1.00	101.4
243.-248.	24	N2	14.273	0.082	1.3024	0.0074	11.534	0.325	3.12	66.0
252.-258.	26	M2	64.674	0.090	1.1299	0.0016	0.000	0.079	1.73	180.0
262.-265.	14	L2	1.108	0.049	0.6846	0.0305	-21.290	2.567	0.94	-154.5
267.-274.	12	S2	23.854	0.078	0.8957	0.0029	-21.576	0.178	12.36	-134.8
275.-2*5.	38	K2	6.780	0.055	0.9357	0.0075	-17.564	0.463	2.82	-133.5
327.-332.	18	M3	0.274	0.029	0.2786	0.0294	237.592	5.854	1.14	-168.4

```
STANDARD DEVIATIONS    D  12.02     SD  4.19    TD  1.31
O1/K1  1.1441  1-O1/1-K1   0.9756   M2/O1   6.8517
```

Table 4

29 10 0 N -13 26 0 E H 60M

CUEVA DE LOS VERDES (LANZAROTE) GRAVIMETRC LCR. 4

LEAST SQUARE ANALYSIS/VENEDIKOV/74,PROG.SV.-ICET-DUCARME,MELCHIOR,VENEDIKOV
FILTERS ON 30 HRS,NR 102,202,301, ELIM.POWERS D 2 SD 1 TD 1
COMPONENTS S1 O1 S2 N2 M3
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID (SKALSKY)
COMPUTER CENTRE UNIVERSITY COMPLUTENCE, MADRID
COMPUTER IBM 4381 PROCESSED ON 21.09.88

NORMALIZATION FACTOR -1.0000
INERTIAL CORRECTIONS INTRODUCED

TIME INTERVAL 0.8 YEARS 287.4 DAYS 5580 READINGS 8 BLOCKS WEIGHTS
G*** 870711/870813 870908/871003 871011/871013 871110/871129
G*** 871202/880214 880218/880305 880307/880314 880316/880427

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
105.-139.	65	Q1	5.930	0.035	1.1721	0.0068	-0.309	0.379	0.07	-26.7
143.-149.	26	O1	29.958	0.057	1.1338	0.0021	-0.077	0.150	0.68	-176.6
152.-158.	22	NO1	2.363	0.027	1.1372	0.0132	0.156	0.676	0.05	171.8
161.-164.	13	P1	13.621	0.037	1.1077	0.0030	0.428	0.161	0.57	169.8
165.-168.	20	K1	41.296	0.033	1.1113	0.0010	0.581	0.053	1.07	156.8
172.-177.	22	J1	2.404	0.027	1.1572	0.0132	0.098	0.650	0.01	154.3
181.-1*3.	37	OO1	1.251	0.018	1.0990	0.0157	1.964	0.810	0.08	148.8
207.-2*5.	155	M2	63.227	0.406	1.1047	0.0071	1.557	0.345	3.63	151.7

B1= -0.0978 +- 0.0083 B2= -0.0132 +- 0.0070 E= 0.0987 BETA= 187.69

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
207.-23*.	41	2N2	1.476	0.031	1.0175	0.0213	0.205	1.122	0.21	178.5
243.-248.	24	N2	11.122	0.077	1.0150	0.0070	2.387	0.365	1.67	163.9
252.-258.	26	M2	58.038	0.043	1.0140	0.0007	2.829	0.053	8.90	161.2
262.-265.	14	L2	1.605	0.027	0.9921	0.0164	3.654	0.859	0.29	159.6
267.-274.	12	S2	27.073	0.278	1.0167	0.0104	3.674	0.501	4.24	155.9
275.-2*5.	33	K2	7.390	0.059	1.0200	0.0095	3.556	0.469	1.13	156.0

B1= -0.1032 +- 0.0213 B2= -0.0413 +- 0.0213 E= 0.1112 BETA= 201.81

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
327.-382.	18	M3	1.069	0.016	1.0888	0.0159	1.570	0.827	0.10	17.3

B1= -0.0313 +- 0.0285 B2= -0.0048 +- 0.0293 E= 0.0316 BETA= 188.67

STANDARD DEVIATIONS D 1.68 SD 1.30 TD 0.62
O1/K1 1.0201 1-O1/1-K1 1.1988 M2/O1 0.8971

WORKING GROUP ON HIGH PRECISION TIDAL DATA PROCESSING

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DETERMINATION OF SOME PARTICULAR WAVES IN THE EARTH TIDE DATA

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1. Introduction.

Recently Melchior & Ducarme (1986) and Melchior, Crossely, Dehant & Ducarme (1987) (hereinafter MA) have detected, in the observations made by the superconductive gravimeter in Brussels, some new particular waves (hereinafter SW). Their period range is between $13^{h}.166$ and $17^{h}.126$, a most significant wave being observed at $13^{h}.924$.

Evidently SW are of non-tidal origin. In the spectrum they are situated between the D and SD bands, considerably closer to SD .

Briefly the method for the determination of SW used by MA consists in the following. First the signal preliminary determined is subtracted. Then the residual curve thus obtained is submitted to power spectrum analysis.

Here we shall demonstrate another way to study SW which may be used in addition to the research done by MA . We shall present a few preliminary but more or less encouraging results.

We have an information about the periods (frequencies) of SW theoreticaly and/or experimentally (MA) determined. Then it becomes possible, even recomendable, to use the Method of the least squares to estimate the elements of SW . The main advantages of this method are (i) we can create and use a clear and flexible mathematical model (or models) and (ii) the results are accompanied by well defined estimates of their precision.

The physical sense of SW is not the object of our paper. We can only refer to the papers of MA, Gunn & Aldridge (1987), Aldridge & Lumb (1988) where one may find an interpretation and a corresponding bibliography. We shall simply note that SW have an extremely low power - amplitudes of the order of a few nanogals (10^{-12} of the gravity) - and that they may have variable and unstable amplitudes, phases and frequencies.

2. The analysis model.

The model of the useful tidal signal in the method of analysis (Venedikov, 1966, 1978) is

$$L(t) = \sum_{j=1}^{m} \xi_j \cdot \sum_{i=a_j}^{b_j} H_i \cos (P_i + w_i t)$$

$$+ \eta_j \cdot \sum_{i=a_j}^{b_j} H_i \sin (P_i + w_i t) \qquad (1)$$

where

$L(t)$: tidal signal at time t ,

i : index or sequential number of a given tide,

H_i : theoretical (undeformable Earth) amplitude,

P_i : theoretical phase for an initial epoch for which $t = 0$,

w_i : angular velocity,

a_j, b_j : the tides with indices

$$a_j \leq i \leq b_j \qquad (2)$$

shape a tidal group j $(j = 1, 2, \ldots m)$; it is supposed that all of them have one and the same tidal parameters δ_j and $\varkappa_j$, and

$$\xi_j = \delta_j \cos \varkappa_j , \quad \eta_j = - \delta_j \sin \varkappa_j \quad . \qquad (3)$$

The quantities (3) are the unknowns which are determined by the analysis. From them we obtain δ_j and $\varkappa_j$.

Let us suppose that the tidal record incorporates an additional wave of type SW whose angular velocity is w . Analytically this can be represented by the addition to the right side of the expression (1) of a term like

$$\Delta L(t) = \xi \cdot H \cos (P + wt) + \eta \cdot H \sin (P + wt) \quad . \qquad (4)$$

This term is composed in such a way in order to be similar to the representation of the tidal waves in (1). Namely H and P are included as theoretical amplitude and phase but they can be choosen absolutly arbitrary. The quantities ξ and η are unknowns about which we have in mind expressions similar to (3). If we obtain ξ and η through a processing of the data, then the observed amplitude h of the wave SW will be calculated after

$$\delta^2 = \xi^2 + \eta^2 \quad \text{and} \quad h = \delta . H \quad . \tag{5}$$

In MA the periods are given, naturally, with a limited precision, for example $13^{h}.924$. Evidently one may expect that the last digit is not certain. The uncertainty arises if we suppose that the waves SW change with time. That is why we have made the following numerical speculation.

The single wave (4) is replaced by the sum of 5 waves with very close periods/angular velocities. If T is a given period, these 5 waves have the periods T - o.0010, T - 0.0005, T, T + 0.0005 and T + 0.0010.

In the computer's program SV there are 504 tides from the Cartwright-Teyler-Eden development plus 3 "meteorological" waves (see Table II). All these waves are enumerated by the index i = 1, 2, ... 507. Thus the five waves have the indices i = 508,... 512. The sum through which the representation (4) is replaced looks like

$$L(t) = \xi \sum_{i=508}^{512} H \cos\,(P+w_i t) + \eta \sum_{i=508}^{512} H \sin(P+w_i t) \tag{6}$$

where the arbitrary H and P remain constants for all 5 waves, while w_i are slightly different

For the period $T = 13^h.924$ we have choosen

Table I

i	periods	w_i
	h	o
508	13.9230	25.8565
509	13.9235	25.8556
510	13.9240	25.8546
511	13.9245	25.8537
512	13.9250	25.8528

3. Filters for the determination of SW.

The first stage of the analysis consists in the filtration of independent intervals (intervals without overlapping) from the record which is processed. The length of the intervals most often used is 48 hours but the program SV allows its arbitrary choice, for example 36 hours. In the present study for the determination of SW we have choosen two lengths: 36 and 42 hours. The first one was choosen as we have used it frequently for the determination of the usual D and SD tides, and the second one - as it is approximately multiple (3 times) of the period 13.924.

The filters were constructed through consecutive orthogonalization (Venedikov, 1978) The tables II represent the response (columns SW1) of the filters used. The first of the columns SW1 is for the even filter, the second one - for the odd filter. Only the most important components are included in the tables.

The filters eliminate an arbitrary linear drift independently for each one of the filtered intervals. Their response is just 1.00000 for the component i = 508, i.e. for the first of the 5 waves SW. The D tides are reduced through the perfect elimination of both O1 and S1 . However, as the precision for the determination of SW must be a very high one, generally the reduction of D is not satisfactory (Q1 , K1). This is taken into account in the analysis.

SW are very close to SD and it is not possible to be separated from them within intervals of such a length. Something more, the response of the filters for SD is higher than 1.00000 . This is because SW are between D and SD . If we conceive SW , D and SD as n-dimensional vectors (n = 36 or 42) D and SD are approximately orthogonal and SW lays approximately in the hyperplane (D,SD), between D and SD . The orthogonalization of SW to the D components O1 and S1, through which we obtain filters eliminating O1 and S1, turns SW closer to SD than to the initial position of SW.

4. Some results.

We have processed the series of data obtained by the superconducting gravimeter in Brussels. The data were kind ly given at our disposal by prof. Melchior with the help of Mlle De Becker. They cover a 5.6 years interval: 21.04.1982 - 26.11.1987, a little bit larger than the series used by MA.

Table III represents an output from the program SV for SW with a mean period $T = 13\overset{h}{.}924$ (see Table I). It can be seen which tidal groups are included in the computation, i.e.

how is composed the model (1).

At first there is one group indicated by K1 which comprises all 205 D tides. It appeared to be necessary to include this group in the model because the separation of SW from D, as it was stated in the previous paragraph, is not a perfect one. This is proved by the fact that the δ factor obtained for this group is a significant one (1.245 ± 0.098). At the same time it is not necessary to use a more detailed separation because D as a whole is strongly suppressed by the filters.

Then there are 13 SD groups - the most detailed separation which is used by the tidal analysis. One can see that we have obtained a very good determination of these tides. After that there is a single group M3 composed by all TD waves. The filters were not designed to eliminate TD.

At the end there is the group of five SW waves (Table I) The digits printed as the argument number of Doodson are of no meanings. Here one can notice that the intermediately value $\delta = 0.31$ is just 100 times the observed amplitude $h = 0.0031$ μgal = 3.1 nanogal. This is because the arbitrary value of the "theoretical" amplitude H in (4) and (6) was choosen $H = 100$.

The extremely high precision of near 1 nanogal is due to the accumulation in the model (6) of 5 waves with very close periods (Table 1). It can be accepted as a realistic only if the spectrum is a continuous one over the band defined by the five waves (discussion at the time of the meeting of the Working group on high precision tidal data processing and particular remark by prof. Jentzsch). In fact if we want to attribute the result to a single wave, i.e. a single line in the spectrum we have to multiply both the amplitude and its R.M.S. (mean square error) by a factor near 5 . For differences between the 5 frequencies as in Table I the factor is 4.8 .

In Table IV the amplitudes with their R.M.S. (after a multiplication by 4.8) for several periods are given. These are some of the periods obtained by MA. An exception is the first period in the Table IV . It has been choosen as the closest period which can be separated from 13.924 within a record of 5.6 years. It is an important fact that there is not a significant amplitude at this period.

If we use the Student's criterea the amplitude is a significant one only at 13.924. Thus we have only a partly confirmation of the results obtained by MA.

Nevertheless we are more inclined to consider this as encouraging. Our results are to be considered as preliminary ones and they were obtained mainly in order to develop the technology for this way of processing. We realize that there is still room for perfectioning the computation : (i) modification of the program in order to make easier and more operational the work when new particular waves are searched, (ii) better and more motivated choice of the filters including their lengths and eliminated components, (iii) perfectioning of the model , (iv) separation of the whole interval of the data on shorter intervals delimited by strong earthquakes as in MA, (v) introduction of a new tide-potential development, (vi) consideration of the air-pressure influence, (vii) experimentation on other long series of data etc.

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We express our thanks to prof P. Melchior for initiating

our research on this interesting and important delicate problem as well as for giving at our dispostal the high precision data from the superconducting gravimeter in Brussels.

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FILTERS LENGTH 35 NR 102,501,202, **Table II.A**

i	waves			w_i	SNI	SW1
				o		
0	056	554	SA	0.0411	0.000005	0.000000
13	057	555	SSA	0.0821	0.000020	0.000000
16	058	554	STA	0.1232	0.000044	0.000000
32	065	455	M	0.5444	0.000863	0.000014
50	073	555	MSF	1.0159	0.002975	0.000091
64	075	555	MF	1.3300	0.003469	0.000114
83	083	655	MSTM	1.5690	0.006977	0.000328
95	085	455	M11	1.8424	0.007617	0.000375
111	093	555	MSSM	2.1153	0.012333	0.000783
122	0*5	455	OA3	2.6363	0.018872	0.001506
129	107	755	107	11.3304	0.023233	0.010434
133	115	855	115	12.0099	0.020151	0.007775
137	117	655	S1S2	12.3328	0.018960	0.007359
140	119	455	119	12.4556	0.017775	0.006944
148	125	755	221	12.8543	0.011654	0.004717
155	127	555	S1S1	12.9271	0.010628	0.004325
160	129	555	129	13.0000	0.009621	0.003940
166	134	656	134	13.5570	0.005150	0.002178
174	135	645		13.3065	0.004720	0.002002
175	135	655	O1	13.3387	0.004704	0.001952
182	136	654	135	13.4397	0.004252	0.001811
185	137	455	KO1	13.4715	0.003928	0.001674
190	138	454	133	13.5120	0.003500	0.001500
195	143	755	143	13.8702	0.001473	0.000208
197	144	556	144	13.9020	0.000250	0.000115
201	145	545		13.9408	0.000014	0.000065
202	145	555	O1	13.9453	0.000000	0.000000
210	146	554	145	13.9841	-0.000243	-0.000108
214	147	555	TAO1	14.0252	-0.000460	-0.000209
221	153	655	153	14.4140	-0.001695	-0.000779
226	155	455		14.4374	-0.001728	-0.000799
231	155	655	MO1	14.4387	-0.001727	-0.000799
237	157	455	O111	14.5095	-0.001636	-0.000784
245	162	556	P11	14.8179	-0.000520	-0.000249
246	163	555	P1	14.9339	-0.000272	-0.000131
252	164	556	S1	15.0000	0.000000	0.000000
259	165	545		15.0339	0.000280	0.000135
260	165	555	K1	15.0411	0.000297	0.000143
261	165	565		15.0433	0.000313	0.000151
265	166	554	PS11	15.0821	0.000613	0.000299
270	167	555	P111	15.1232	0.000965	0.000465
276	173	655	TETA	15.5120	0.005553	0.002777
283	175	455	O1	15.5834	0.006633	0.003361
300	183	555	SO1	16.0570	0.015210	0.008441
309	185	555	OO1	16.1391	0.013277	0.009574
310	185	565		16.1413	0.013334	0.009606
316	193	455	193	16.6013	0.032295	0.017492
323	195	455	NO1	16.6335	0.035219	0.019190
328	1*3	555	1A3	17.1550	0.054654	0.030797
334	209	655	209	26.4079	1.051932	1.092043
337	217	755	217	26.8795	1.033733	1.168678
339	219	555	219	26.9523	1.035040	1.180279
343	225	655	ON2	27.3510	1.120747	1.242341
349	227	655	EP52	27.4258	1.124377	1.253392
352	229	455	229	27.4907	1.128826	1.264345
360	235	755	2N2	27.8954	1.147131	1.322355
361	236	556	235	27.9271	1.143367	1.326830

FILTERS LENGTH 50 NR 102,501,202,

Table II.A (continuation)

i	waves			w_{i_o}	SW1	SW1
307	237	555	M32	27.9582	1.149884	1.332575
370	238	554	233	28.0093	1.151339	1.338280
371	239	555	235	28.0411	1.152423	1.342667
377	44	656	244	28.3987	1.162011	1.390239
385	245	655	M2	28.4597	1.162832	1.395480
390	246	654	246	28.4803	1.163523	1.400674
392	247	455	M32	28.5126	1.164045	1.404661
397	248	454	248	28.5556	1.164655	1.409768
402	253	755	253	28.9113	1.167133	1.452069
404	254	556	254	28.9430	1.167175	1.455632
409	255	545		28.9319	1.167093	1.459943
410	255	555	M2	28.9341	1.167092	1.460137
417	256	554	255	29.0252	1.166972	1.464685
423	257	555	263	29.0662	1.166725	1.469127
426	263	655	LA18	29.4556	1.161512	1.508300
430	265	455	L2	29.5285	1.159321	1.515016
433	267	455	267	29.6106	1.157459	1.522345
441	271	557	271	29.9179	1.145552	1.547419
442	272	556	T2	29.9589	1.145259	1.550483
444	273	555	52	30.0000	1.143493	1.553477
447	274	554	274	30.0411	1.141665	1.556401
453	275	555	K2	30.0321	1.139772	1.559255
454	275	565		30.0343	1.139637	1.559406
465	285	655	255	30.5557	1.111133	1.586815
467	285	455	L1A2	30.6265	1.108259	1.590194
475	293	555	293	31.0980	1.071561	1.606119
481	295	555	2K2	31.1302	1.064233	1.607815
486	2*5	455	2A5	31.7245	1.039835	1.610682
488	327	655	327	41.9159	-0.424433	-0.317834
489	335	755	335	42.3374	-0.432930	-0.405929
492	345	655	345	42.9518	-0.432216	-0.495237
493	355	555	15	43.4702	-0.423705	-0.570037
496	365	455	365	44.0265	-0.399133	-0.629327
502	375	555	375	44.5742	-0.367733	-0.673008
505	382	555	55	45.0000	-0.337370	-0.694948
506	455	555	M4	57.9582	0.064137	0.482259
507	491	555	54	60.0000	-0.093641	0.313101
508	111	111	5M1	25.8505	1.000000	1.000000
509	111	111	5M2	25.8556	0.999935	0.999844
510	111	111	5M3	25.8546	0.999812	0.999687
511	111	111	5M4	25.8557	0.999718	0.999531
512	111	111	5M5	25.8528	0.999624	0.999375

FILTERS LENGTH 42 NR 102,501,202,

Table II.B

i	waves			w_i^o	SW1	SW1
5	056	554	SA	0.0411	0.000011	0.000000
13	057	555	SSA	0.0821	0.000042	0.000000
16	058	554	STA	0.1232	0.000095	0.000000
32	065	455	MM	0.5444	0.001847	0.000030
50	073	555	MSF	1.0159	0.006363	0.000190
64	075	555	MF	1.0980	0.007422	0.000240
83	083	655	MSTM	1.5696	0.014910	0.000688
93	085	455	MTM	1.6424	0.015274	0.000786
111	093	555	MSQM	2.1139	0.026319	0.001637
122	[illegible]	455	[illegible]	2.6383	0.040164	0.003144
129	107	755	107	11.8384	0.053210	0.019295
133	115	855	115	12.3099	0.037583	0.014224
137	117	655	SIGQ	12.3828	0.035237	0.013440
140	119	455	119	12.4550	0.033025	0.012660
143	125	755	2Q1	12.8543	0.021460	0.008517
155	127	555	SIG1	12.9271	0.019518	0.007795
160	129	555	129	13.0000	0.017637	0.007088
166	134	656	134	13.3576	0.009373	0.003882
174	135	645		13.3965	0.008581	0.003566
175	135	655	Q1	13.3987	0.008537	0.003548
182	136	654	136	13.4397	0.007725	0.003222
185	137	455	RO1	13.4715	0.007115	0.002975
190	138	454	138	13.5126	0.006343	0.002664
195	143	755	143	13.8702	0.000847	0.000360
197	144	556	144	13.9020	0.000466	0.000202
201	145	545		13.9408	0.000024	0.000011
202	145	555	O1	13.9430	0.000000	0.000000
210	146	554	146	13.9841	-0.000434	-0.000189
214	147	555	TAU1	14.0252	-0.000837	-0.000366
221	153	655	153	14.4140	-0.002951	-0.001350
226	155	455		14.4374	-0.003043	-0.001381
231	155	655	NO1	14.4967	-0.003041	-0.001381
237	157	455	CHI1	14.5695	-0.002952	-0.001353
243	162	556	PI1	14.9179	-0.000904	-0.000425
246	163	555	P1	14.9589	-0.000473	-0.000223
252	164	556	S1	15.0000	0.000000	0.000000
259	165	545		15.0389	0.000435	0.000230
260	165	555	K1	15.0411	0.000514	0.000244
261	165	565		15.0433	0.000543	0.000257
265	166	554	PSI1	15.0821	0.001070	0.000509
270	167	555	PHI1	15.1232	0.001658	0.000795
276	173	655	TETA	15.5126	0.009431	0.004657
283	175	455	J1	15.5854	0.011384	0.005622
300	183	555	SO1	16.0570	0.027194	0.013909
309	185	555	OO1	16.1391	0.030578	0.015735
310	185	565		16.1413	0.030671	0.015785
316	193	455	193	16.6013	0.053135	0.028304
323	195	455	NU1	16.6835	0.057833	0.030963
328	1?3	555	1X3	17.1550	0.033274	0.048876
334	209	655	209	26.4079	1.003413	1.045122
337	217	755	217	26.8795	0.955571	1.074889
339	219	555	219	26.9523	0.953471	1.078706
343	225	655	3N2	27.3510	0.917796	1.095681
349	227	655	EPS2	27.4238	0.914173	1.098048
352	229	455	229	27.4967	0.910318	1.100183
360	235	755	2N2	27.8954	0.945177	1.107665
361	236	556	236	27.9271	0.942832	1.107950

FILTERS LENGTH 42 NR 102,501,202,

Table II.B (continuation)

i	waves			w_i	Sw1	Sw1
				o		
367	257	555	M02	27.9562	0.933855	1.108250
370	258	554	253	28.0093	0.936753	1.108472
371	259	555	253	28.0411	0.934313	1.108591
377	244	655	244	28.3967	0.903937	1.106665
385	245	655	N2	28.4397	0.900179	1.106058
390	246	654	245	28.4808	0.896307	1.105371
392	247	455	N02	28.5126	0.893264	1.104784
397	248	454	243	28.5536	0.889277	1.103955
402	253	755	253	28.9113	0.851906	1.093333
404	254	556	254	28.9430	0.848351	1.092093
409	255	545		28.9819	0.843930	1.090512
410	255	555	M2	28.9841	0.843729	1.090420
417	256	554	255	29.0252	0.839039	1.088666
420	257	555	250	29.0662	0.834290	1.086831
426	265	655	LAMB	29.4556	0.785515	1.065445
430	265	455	L2	29.5285	0.777049	1.060647
438	267	455	257	29.6100	0.766139	1.054938
441	271	557	271	29.9179	0.723892	1.030800
442	272	556	T2	29.9589	0.713053	1.027245
444	275	555	S2	30.0000	0.712165	1.023613
447	274	554	274	30.0411	0.705239	1.019905
455	275	555	K2	30.0821	0.700271	1.016120
454	275	565		30.0843	0.699949	1.015915
465	285	655	285	30.5537	0.629070	0.967332
467	285	455	EIA2	30.6265	0.617700	0.958940
475	293	555	293	31.0980	0.541966	0.899398
481	295	555	2N2	31.1802	0.528457	0.888137
486	2*5	455	2X5	31.7245	0.437537	0.807377
483	327	655	327	41.9159	-0.035249	-0.333671
489	335	755	335	42.3374	-0.049826	-0.298592
492	345	655	345	42.9318	-0.011289	-0.250491
496	355	555	M3	43.4762	0.023462	-0.196064
499	365	455	365	44.0205	0.065090	-0.137344
502	375	555	375	44.5742	0.003525	-0.075385
505	382	555	S3	45.0000	0.117756	-0.027578
506	455	555	M4	57.9682	-0.034753	-0.210839
507	491	555	S4	60.0000	-0.006443	-0.183146
508	111	111	SM1	25.8565	1.000000	1.000000
509	111	111	SM2	25.8556	0.999933	0.999915
510	111	111	SM3	25.8546	0.999960	0.999831
511	111	111	SM4	25.8537	0.999943	0.999746
512	111	111	SM5	25.8528	0.999932	0.999661

STATION BRUSSELS VERTICAL COMPONENT BELGIUM **Table III**
GRAVIMETER SUPERCONDUCTIVE, OBSERVATOIRE ROYAL DE BELGIQUE
50 48 0 N 4 22 0 E H 101M

P.MELCHIOR

LEAST SQUARE ANALYSIS/VENEDIKOV/74,PROG.SV.-ICET-DUCARME,MELCHIOR,VENEDIKOV
FILTERS ON 35 HRS,NR 102,301,202, ELIM.POWERS SW 1
COMPONENTS S1 O1 SW1 S2 N2
POTENTIAL CARTWRIGHT-TAYLER-EDDEN / COMPLETE DEVELOPMENT
COMPONENTS ORIENTATED TOWARDS THE ELLIPSOID (SKALSKY)
COMPUTER CENTRE UNIVERSITY COMPLUTENCE, MADRID
COMPUTER IBM 4381 PROCESSED ON 15.09.88

NORMALIZATION FACTOR 0.1000
INERTIAL CORRECTIONS INTRODUCED

TIME INTERVAL 5.5 YEARS 2011.0 DAYS 48168 READINGS 3 BLOCKS NO WEIGHTS
G*** 820421/820525 820602/851101, 851115/871126

WAVE GROUP ARGUMENT	N	WAVE	ESTIMATED AMPL.	R.M.S.	AMPLIT. FACTOR	R.M.S.	PHASE DIFF.	R.M.S.	RESIDUALS AMPL.	RESIDUALS PHASE
105.-1*3.	205	K1	53.350	4.183	1.2452	0.0977	-0.097	4.467	4.61	-1.1
207.-224.	21	EPS2	0.252	0.004	1.1550	0.0169	3.643	0.650	0.02	110.8
233.-236.	10	2N2	0.851	0.004	1.1520	0.0053	3.363	0.266	0.06	114.4
237.-23*.	10	MU2	1.005	0.004	1.1932	0.0044	4.112	0.211	0.08	70.7
243.-245.	13	N2	6.741	0.004	1.1730	0.0007	3.187	0.033	0.38	80.4
246.-248.	11	NU2	1.277	0.004	1.1700	0.0036	2.662	0.176	0.06	81.0
252.-258.	20	M2	35.757	0.004	1.1911	0.0001	2.467	0.006	1.78	59.7
262.-264.	5	LAM2	0.255	0.004	1.1437	0.0173	3.427	0.862	0.02	105.1
265.-267.	12	L2	0.989	0.003	1.1425	0.0033	2.505	0.164	0.05	110.5
271.-272.	2	T2	0.934	0.004	1.2021	0.0046	1.128	0.216	0.04	29.6
273.-273.	4	S2	16.902	0.004	1.2102	0.0003	1.132	0.013	0.77	25.6
274.-277.	12	K2	4.567	0.003	1.2070	0.0008	1.202	0.039	0.20	28.5
282.-285.	15	ETA2	0.253	0.003	1.1834	0.0141	-0.142	0.678	0.01	-5.9
292.-2*5.	14	2K2	0.072	0.002	1.2348	0.0358	-1.943	1.593	0.01	-19.4
327.-375.	17	M3	0.402	0.010	1.0788	0.0264	0.172	1.393	0.03	2.2
111.-111.	3	SW1	0.0031	0.0012	0.31	0.12	256.77	22.96	0.01	-166.4

STANDARD DEVIATIONS SW 0.31

Table IV

FILTERS LENGTH	36		42	
PERIODS	AMPLIT.	R.M.S.	AMPLIT.	R.M.S.
h 13.918	7.6	± 5.8		
13.924	14.9	5.6	13.0	± 6.2
14.066	2.9	8.1	7.2	5.3
14.228	20.6	13.9	16.3	14.4
14.394	10.6	7.6		

The unit of the amplitudes is nanogal.

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